Reflections on a lifetime's work in oil industry geoscience

Koen Weber, professor in production geology at the Technical University, Delft, retired at the end of last year. To mark the occasion and honour his career both as an academic since 1984 and previously as a distinguished research engineer with Shell, a symposium on production geology was held in Delft. The seminar included contributions from a number of present and past colleagues and former students. We publish here Professor Weber's own farewell address entitled 'Adventures in Soft Science', one man's view of where the geosciences have reached at the beginning of the new millennium enriched by the experiences of a lifetime.

In 1985 I choose as title for my inaugural speech: *Production geology, tangent plane between geologist and engineer*. In this valedictory address I want to sketch the important role that mining engineers can play in forming a bridge between geologists and engineers.

At the beginning of my career petroleum engineers tended to be physicists with a strict observance of physical principles and a deep belief in the power of mathematics. Something that couldn't be calculated or measured to a few decimals behind the comma should be considered to be a dubious property, better left alone. Geologists at this time tended to take the opposite view. Virtually nothing was measured and most geological processes were poorly understood and rarely under-built by solid physical theories. Statements were vague and full of jargon, alien to the engineer's ear.

Mining engineers form a hybrid group situated between physicists and geologists. Their work always involves problems related to geological features which are not fully understood and for which there is no representative data base. Thus there is need for estimating ranges of parameter values and for the determination of the significance of the inherent uncertainty levels towards the economics of a project. If deemed important the missing data have to be obtained either directly from the field or indirectly via analogue examples.

Typically decisions have to be taken on the basis of incomplete information or via probabilistic modelling and decision tree type methods. This implies the use of adequate safety margins and building in a maximum of flexibility in the planning stage. Also one has to plan the data collection during the early stages of the project to reap maximum benefit from the learning curve during the execution. Safety margins should not be carried too far as was shown by the bridges on Sumatra built by Delft mining engineers before World War Two. When these had to be blown up to slow the Japanese advance, this proved to be almost impossible.

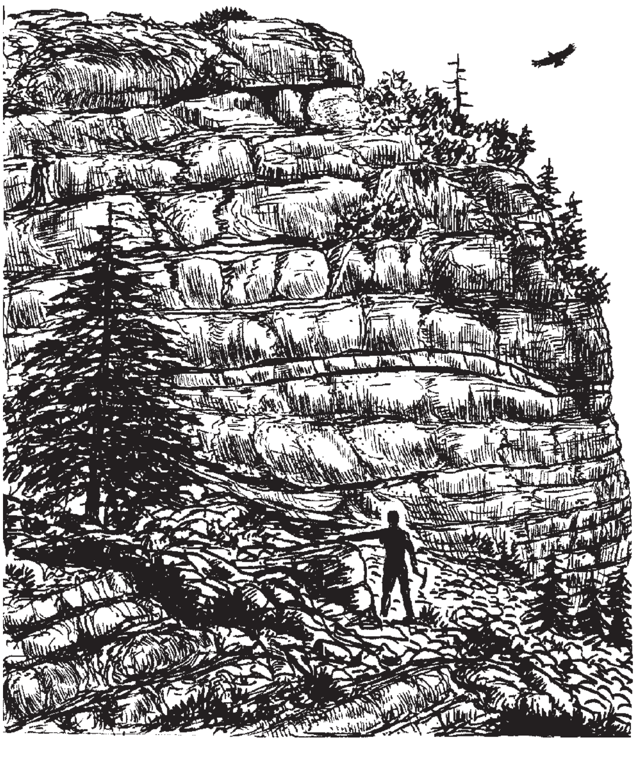
This example also demonstrates the reluctance of the mining engineer to believe in the outcome of theoretical calculations, being used as they are to the unpredictable surprises prepared by nature. Thus the world of the mining engineer is one of calculated risk. One must be inventive, pragmatic and sufficiently courageous to reach the necessary operational decisions at the right time. This doesn't guarantee a glorious career, because in my experience high positions often go to people who systematically avoid having to take any significant decision. However, it will certainly result in a very satisfactory working life.

With this introduction, the title of this talk will begin to make sense. The essence of the mining engineer's work in production geology is the skill with which he or she can take calculated risks based mainly on soft information using rather soft theories. I want to demonstrate this in a light-hearted manner by way of two examples out of my own experience.

These examples are also meant to illustrate the philosophy of my teaching programme in Delft. This emphasizes a broad versatile approach comprising many disciplines, using data with many different origins and employing theories ranging from exact to pretty soft. In the meantime we should not forget that production geology is a romantic profession which involves many journeys to interesting places, meeting other people, seeing the wonders of nature and doing a bit of treasure hunting at the side. It is necessary to be keenly interested in anthropology and ethnography to ensure fruitful co-operation. Another useful requisite is to be critical about established practice and methods which, as you will see, can result in absurd situations which however may have escaped detection for a long time.

The first task I was given in Shell in 1960, was to describe the Gach Saran field in Iran with respect to its reservoir rock properties and fracture system and to determine its oil-in-place. Cores from several wells had been sent to the Shell laboratory. It is a giant field, 70 km long, situated close to the higher foothills of the Zagros mountains. Although several of the Iranian fields had been discovered before the First World War, nobody had seriously tried to make a realistic estimate of oil-in-place in the gigantic structures. Logging and coring started only some time after the Second World War. The area was known for its massive blow-outs when sudden total loss of circulation was experienced when drilling into a major fault zone.

The idea was that the Tertiary Asmari reservoir rock had an average porosity of some 10% of the fracture porosity amounted to 1% of rock-bulk volume. This led to an estimate of recoverable reserves of about 2% of rock-bulk volume which for these 250 to 500 m thick reservoirs was a very large volume. Nobody was very happy with these figures but it was only after the fall of Mosadek, when a consortium of oil companies took over operations, that a serious research programme was started.



In 1959 Shell was appointed as technical advisor for production development. Initially research centred on a study of oil drainage from a reservoir composed of separate limestone blocks. A theoretical model had been proposed consisting of a pile of cube- shaped blocks floating in space and leading an independent capillary life. This highly unrealistic model had one merit that endeared it to the reservoir engineers: it allowed the computation of oil displacement as a function of block height, capillary pressure curve and wettability to oil and water. Unfortunately block height in the field was unknown and wettability could not yet be measured with any accuracy.

I was given a beautiful microscope and started studying the cores making use of the well established Tertiary sequence of foraminifera and the famous Archie classification for rock texture. The Asmari clearly consisted of a series of regressive cycles ranging from marl to dolomite and often capped by thin anhydritic zones. Log correlation was fairly easy. However, because the first seven wells had not been logged, there were gaps in the data coverage. For all wells, cuttings had been collected and stored for every 2 ft of borehole. We developed a method to measure the porosity on cuttings and combined with the Archi classification, this would allow us to recognise rock types and establish porosity distribution.

It was decided that I should go to Iran for a couple of months to study the cuttings and to take a good look at the Asmari outcrops to obtain an idea of block heights and fracture porosity. Although it was pretty cold in Iran during my trip, I didn't complain about my tropical allowance. My reception in Teheran was almost like 1001 Nights: after customs, I was met by a beautiful blonde woman who led me to a Rolls Royce-like car. It just might have been that the bulge to be seen under my raincoat (three boxes of Carl Upmann cigars, specially ordered by telex by the managing director, Mr Berlin) had something to do with this!

When I reached the fairly remote Gach Saran field I immediately went enthusiastically to the old field laboratory which was used as sample storage. It wasn't difficult to locate the cuttings of the older wells. They were in glass tubes stacked in a big packing crate because the cupboard space was used for the newer wells. My two workers started to unpack but after reaching the level of well-15 they cut their fingers on broken tubes. Compaction, like in nature, had taken place and lower down there was just a mixture of pieces of glass and cuttings.

Badly disappointed I next turned my attention to the thin sections which I knew had been made for every sample. They were neatly labelled in nice cupboards. However, here the heat combined with leaking resin had resulted in the formation of solid blocks of amalgamated thin sections. Rather disillusioned I decided that I had better study the sampling procedure first before spending more time on the cuttings. I went to the rig drilling the well Gach-Saran-33 and watched the mud boy cleaning his 16 partition sample box meticulously. Next he went to the Shale Shaker which was already piled high with cuttings. With an elegant swing he slammed a shovel of cuttings over the box. After carefully smoothing, he then took the box to the well-site petroleum engineer. He packed each partition into a linen bag, each labelled as to its alleged original depth.

A geologist collected the bags and brought them to the laboratory for thin section preparation. The cutting picking guru selected a few pieces from each tray, carefully selecting those fragments which he knew from experience to yield nice thin sections. Unfortunately, nobody had told him that these pieces usually consisted of fossil barren dolomite the brittle nature of which results in cuttings. Except in the rather rare occasions that a sample didn't contain any dolomite would a fossiliferous limestone shard be taken. No wonder that I could make no sense out of the stratigraphic sections in comparison with my own log correlations.

After experiencing a quite frightening earthquake which killed several people in the nearby village, I went on horseback to the famous Kuh-i-Asmari. This is a perfect outcropping Asmari anticline on trend with the oldest field Masjid-i-Suleiman. There, two geologists had set up camp for a long winter campaign of fracture studies. One of them, a big American, John Sangree, was later to become famous through his sequence stratigraphic work. He employed a strange system of crew selection.

Being given illiterate workers, not capable of carrying out measuring work, he loaded them up with rock samples until they would desert. Then he would ask for replacements in the vain hope of getting better ones. These early fracture studies were fairly amateurish and mostly consisted of counting numbers of fractures per ft per length of outcrop. However, techniques improved and understanding grew. I was very much helped by the excellent rock mechanical training I received from Dr Gramberg of our faculty, and because of that I was able to suggest more appropriate measuring schemes.

It is interesting to mention that the fracture studies in Iran intermittently lasted until 1978 when a splendid final report was written. By chance this coincided with the ultimate severance of relations between Shell and the Iranian government! However, I hear that soon a new venture of Shell will go ahead and I know where at least one of those reports is.

A combination of outcrop and core studies finally led to reasonably realistic figures for fracture porosity. For the Gach Saran field the fracture porosity at the crest is of the order of only 0.2% of rock-bulk volume while down flank this value gradually dwindles to some 0.03%. Very prominent in the outcrops are extensive axial faults, marked by metre-wide brecciated zones and dense fracture swarms. A well penetrating such a fault zone would experience almost instantaneous loss of circulation but the reward would be a huge production capacity.

This situation also explained the lassitude towards the cutting collection in the reservoir. The major problem and risk was the setting of casing just above the reservoir. At this stage the geologists would virtually sit on the shale shaker but as soon as casing was set everybody would relax. A new crestal well was planned for Gach Saran to significantly increase offtake. Asked to make a suggestion I projected all major mud losses of the previous wells on a cross-section in the area where the well was planned. This was the time prior to availability of any useful seismic in this region.

This crude method nevertheless revealed a zone in which a major fault zone was likely to be encountered high up in the reservoir. A location was agreed and we went out to build a cairn on the spot. The surveyor was on leave and none of the five local geologists could use a theodolite. Again the mining engineering training of those days came to the rescue as we were adequately trained for surveying both above and below ground. To compensate for their ignorance I used the geologists as markers during the survey. Picking up the first stone for the cairn I was almost bitten by three large scorpions resenting the disturbance of their environment. The subsequent well Gach Saran-34 experienced total loss of circulation after penetrating only 5 m of Asmari and produced at the incredible rate of 64 000 b/d.

It finally took nearly four years to calculate reliable oil-in-place figures for the Gach Saran field and to obtain a good idea of the distribution of rock quality. This was the time when considerable improvements were made in quantitative petrophysical analysis and also in carbonate rock sedimentology. I had the luck to be associated with authorities in this field like James Lee Wilson and Bruce Purcer. The oil-in-place proved to be no less than 37 billion barrels.

While in Iran I made long trips in the weekends to study archaeological sites and do some clandestine digging. One day coming down from the mountains, I noticed the faint outline of streets in the valley, marked by slight variations of vegetation highlighted by the low sun. Digging in the corner of a buried house wall I discovered pottery fragments and underneath a silver drachma of Alexander the Great. I have the fondest memories of these weekends in the wild almost deserted mountains, seeing bears, wolves, and mountain sheep. I still have a little carpet from the Qasgai nomads whose camp I visited. I noted innumerable caves that still beg to be excavated. What a wonderful place to work in.

For the next example we stay closer to home. The Leman gas field is situated near the Norfolk coast in the North Sea. It is the largest gas field in the region, with reserves of about 300 billion m^3. The reservoir is the Rothliegendes Sandstone Formation which in this region is almost entirely composed of large aeolian dune cross-bed sets. Inflow performance of the wells was much lower than the arithmetic average of the core permeabilities would indicate. The reservoir engineers than started to use the geometrical average permeability which brought the production predictions a bit closer.

However, this is equivalent to considering the permeability to be randomly distributed and this is certainly not the case. The real reason is the anisotropic nature of the formation. With the mini-permeameter, which we had developed with

this purpose in mind, we started to investigate the heterogeneities in the Rotliegendes reservoir. We measured the contrasting permeabilities of the foreset laminae. In addition we measured oriented permeabilities on cube-shaped samples. These various measurements allowed us to construct graphs of permeability parallel and perpendicular to the laminae which showed that we were dealing with an anisotropy factor of 50 within the cross-bed sets.

With these data one can compute inflow performance into the wells if the lateral continuity of the cross-bed sets is very large. However, there is also the larger scale anisotropy caused by the enveloping bottom-sets of the cross-bed sets. As you can observe in the giant aeolian cross-bed sets in Utah, these are usually poorer sorted, more consolidated and less permeable than the adjacent bore set laminate. To model inflow performance of wells it is necessary to know the lateral dimensions of the cross-bed sets and such data had never been collected. Luckily I had already seen an ideal analogue for the Leman Rotliegendes in northern Arizona in the Canyon de Chelly. There one finds an aeolian Permian sandstone with the same thickness and the same cross-bed set types as in Lemon field.

A short field trip was planned to measure the necessary data. Arriving at the Chelly Canyon National Park I found the motel permanently booked by tourist groups. A kind Navajo girl in the park entrance lodge referred me to the mission post run by a methodist vicar and his family. This was a journey back in time. These marvellous people, reminiscent to me of western movie characters, lent me their schoolroom plus a camp bed for the duration of my stay and I was in business. I had already planned a tight schedule of sketching and photographing a series of cliff faces pre-selected on the basis of detailed maps and photographs in the splendid magazine *Arizona Highways*.

Sketching from the edge of the cliffs in this fantastic landscape I gradually detected more and more Indian ruins of the famous cliff dwellers. Sitting still for hours on end, the animals became curious. Squirrels sat next to me and the vultures spiralled in ever tightening circles. In the evening I worked out my drawings with the aid of Polaroid camera photographs. On Ascension Day a large party of native americans arrived for an all-night service.

Sitting quietly behind my table, only accompanied by a few hungry mice, I was suddenly struck by a soft mumbling sound. Looking around I saw a series of round spots on the fogged windows. Immediately there came a knocking on the door and a string of rosy-cheeked little children filed in. They were a very polite, delightful bunch, thickly bundled against the cold of a May evening on the Colorado plateau. The way to the toilet was via my room but of course the real reason for their activities was the stack of peppermints and chocolates piled on the table. When my goodies were finished the trips to the toilet dwindled fast.

The use of the outcrop data was based on a typical soft science type consideration. Having made a model of the large scale festoon cross-bedding of the Rotliegendes based on small German outcrops, I was struck by the resemblance to fluvial trough cross-bedding. Because that type of cross-bedding shows a clear relationship between thickness, length and width, I reasoned that the same might be true for the aeolian cross-bed sets. Even when the full length or width of a cross-bed set is not explored, this still allows for making an estimate of the width/thickness and length/thickness ratios by measuring exposed lateral continuity, bed thickness and lateral terminations of a bed.

Through a normalizing process one can add up all information and derive average values. Outcrop sections were selected perpendicular to and parallel to the palaeowind direction. An example is provided by the sections measured around the White House ruin area. One can easily see the correspondence to the model of the cross-bedding and the large difference between sections in the two principal directions. Comparing the outcome of the addition of the normalized outcrop measurements for four large sections parallel to the palaeowind direction one can see that the figures are fairly close. For practical purposes one can decide to assume that the average length/thickness ratio is probably close to 200.

For the direction perpendicular to the palaeowind direction a value of about 100 was found. These were the figures entered into the Leman field well performance calculations. Using the porosity/permeability relationships derived from cores and the cross-bed set model from the outcrops it proved possible to calculate satisfactory matches with actual well performance. This resulted in the recognition of several anomalies, most of which had geologically explainable origins. However, several discrepancies were also found to be caused by human error, like poor completion practice.

At this stage an incident occurred. Shell was drilling the D-cluster of wells and the 10th well had just been finished when a terrific storm brewed up. It was decided to remove the jack-up rig in time and drill the remaining four wells the following spring. The D-cluster of wells was contracted to produce initially at 265 million ft^3/d. This was a good opportunity to make ourselves useful and a study of the production capacity of the existing ten wells, which had been suspended without testing, was undertaken. We arrived at a theoretical production capacity at the planned draw-down of 285 million ft^3/d.

Luckily the manager in Lowestoft was an Australian and a natural gambler who took the courageous decision to scratch the four remaining wells, thereby saving $28 million. You may not believe this but the production capacity of the 10 wells together was about 290 million ft^3/d. Thus again soft science may be quite profitable.

Returning now to Delft I would like to refrain from making comments or suggesting all kinds of great ideas for the future. I think it is a bad habit for departing people to try to influence the coming generation. The only real criticism I have is that I think it was a mistake to merge with Civil Engineering and of changing the name of the faculty. I am sure that this has caused a great loss of identity and that this has probably influenced the number of new students significantly.

With respect to the curriculum and research efforts I will be happy if these continue to include outcrop studies. Thus students can be confronted with the reality behind log curves, seismograms and simulation models. This is also the reason for the choice of the two examples in this talk. If some of the students can be inspired by this work to develop a lifelong interest in geology, I see this as a major achievement. For research, it is of importance to persist in certain subjects in order to make significant progress. This matter of continuity is also imperative to the creation of data bases and the foundation of a solid knowledge base on important subjects.

Production geology is not a discipline in which Nobel prizes are likely to be awarded. It is characterized instead by a continuous confrontation with new challenges and the gradual development of improved understanding and methods. As such it is a most interesting, satisfying and adventurous lifetime occupation. This is certainly the case for me and I find myself lucky to have a profession that is also my hobby.

There is still so much to be done and so many interesting subjects waiting to be tackled that I am not planning to retire just yet. I thank the staff of the faculty for the splendid co-operation and I wish you much success in the future. This is particularly true for my successor Stefan Luthi, whom I hand over the torch to guide the students towards the rock. I am sure that our soft science will gradually harden to the level of butter from the deep freeze.

Editorial Note: Prof Koen Weber was subject of a profile in the November 1998 issue of First Break.

Professor Koen Weber in conversation with *First Break* Editor Griff Cordey at the EAGE meeting in Leipzig.